CHOOSING

A

WATERWORKS PUMPING ENGINE

CHOOSING A WATERWORKS PUMPING ENGINE.

A Study of Pumping Engines
With Special Reference to
The Requirements of the City of Evanston.

A Thesis
Submitted in
Partial Fulfillment
of the Requirements
for the Degree
Electrical Engineer

By

Henry Foster Dever
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CHOOSING A WATERWORKS PUMPING ENGINE.

Introduction.

To cover thoroughly the many developments, problems, theories, and viewpoints which have taken form since machinery was first used to supply man with water would be an impractical and unending task. To even go into the question of modern pumping engines thoroughly would be beyond the reach of this thesis. To make this paper of some value to those who want something more concrete on this subject it will begin with a general history of the development of pumps and pumping and narrow down as it progresses to the definite problem of Evanston's waterworks. After the chronological history of pumps and pumping, the subject will be handled more from a commercial basis than a theoretical one. The design of the pump is intentionally omitted in favor of the problems of operation, choice of units and costs. The definite problem of this thesis is the weighing of the factors governing the choice of units (by a cost analysis of the new pump purchased by Evanston) to justify or disagree with the decision to install a reciprocating engine instead of a centrifugal pump.

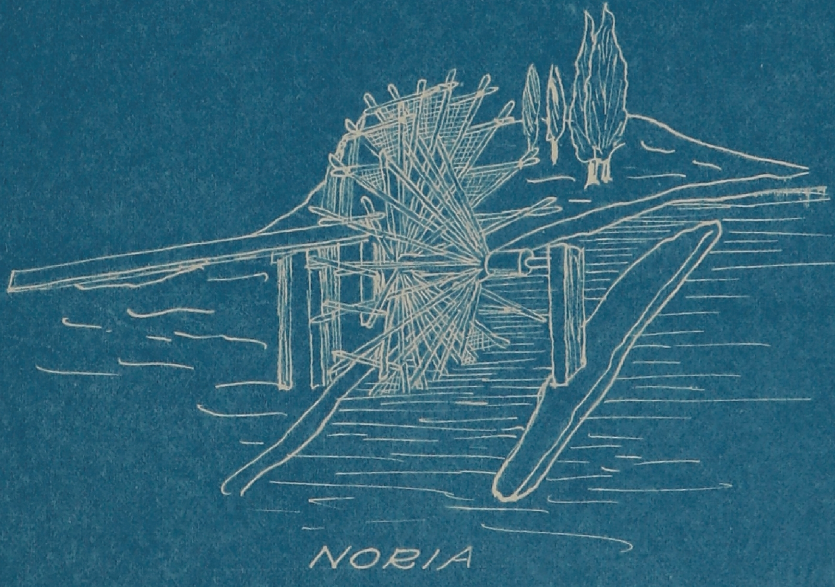
History of Pumps.

Very early in the development of the civilization of man the use of water became sufficiently great to cause man to devise ways of getting it from low places to higher places more conveniently than by carrying it. The first large use of water was for irrigation of pasture lands long before the Christian era. For this purpose the Shadoof was used in Egypt. The Shadoof, which resembles a well-sweep, is simple in form, being nothing more than a balanced lever arm with a bucket on one end which could be raised when filled and emptied at a higher level. To get sufficient elevation to the water, it was sometimes necessary to use Shadoofs in series each elevating the water part of the distance.

In China the Noria was used. This form of machine resembled an undershot water wheel made of bamboo poles. The blades were made of grass matting. As the water in which these were placed was a river and had motion the wheel revolved with it. Attached to each blade was a small bucket which filled as it hit the water and emptied as it got part way to the top of the wheel. The lift was usually small in this case also, but no series arrangement could be used because the motive power was the stream. Experiments on these machines show that two men operating the Shadoof could raise 57,600 cubic feet of water a distance of one foot in ten hours. With the average Noria about 70,000 gallons could be pumped per twenty-four hours. There

PRIMITIVE METHODS

SHADOOF



NORIA

FROM GREENE'S PUMPING MACHINERY

are modern developments of the Noria which are used with fair success on irrigation work today. Another form of Noria is the ancient Persian wheel which was made of a series of pitchers roped to a wheel which, in passing them through a well or pond, filled them and then raised and emptied them. This machine was generally operated by oxen which were made to turn a vertical axis crudely geared to the axis of the wheel.

There were other modifications of these machines and further developments of lesser importance until more was learned of the forces of nature which could be applied to raising water.

It was discovered that air, when heated, enlarged in volume and, when cooled, again contracted. This phenomenon was used by several early inventors to manipulate small pumps of no practical value except as stepping stones to further development. One of these inventions known as a Fountain operated as follows:

See blueprint following page five for sketch of Fountain.

The sun's rays warmed the sphere A, containing air and water. The expanding air forced some water through the syphon B, which returned it to the box D by way of the funnel at C. When the sphere cooled again and the air contracted the water is again pulled into the sphere by way of the pipe E. This pump was described by Hero of Alexandria about 100 years B.C.

Giovanni Baptista della Porta in 1601 suggested using steam in the fountain to produce the force instead of the heating of air. When the water was all discharged it was proposed to create the suction to fill it again by condensing the steam.

In 1630 the king of England granted patents to a David Ramseye to "raise water from low pitts by fire," and to "raise water from low places, and mynes, and coal pitts, by a new waie never yet in use." Greene says there is no record of Ramseye's devices but this indicates possibly the first successful use of heat for raising water.

At the same time water power and animal power were being developed, the most notable instance being the London Bridge Water Works of 1581 where a Dutchman, Peter Morrys, raised water high enough to supply the upper parts of London. His pump was driven by water power of the Thames River, and was really a marvel of success considering the experience of that day.

Captain Agostino Ramelli, an Italian engineer, published a book in 1588 describing his inventions and pumps. His work is noteworthy as it shows that in his inventions he made application of the crank and connecting rod to get reciprocating motion. He also invented one of the first rotary pumps. This pump was an ingenuous gear arrangement but was of little real value.

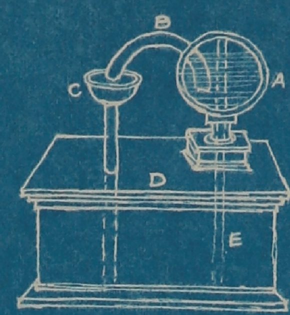
From 1650 to 1700 several improvements were made in the design and theories of pumps and pumping.

It appears that during this time a fair knowledge of the pressure and volume of saturated steam was common. Also the plunger or piston type of pump was brought out. Development included improvement in the city waterworks, invention of the fire engine, and improvements in mine pumps. Among the more famous pumping engineers of this period are Savery, inventor of mine pumps, and Papin, who proposed a plunger type pump with different sized steam and water piston to obviate the necessity of having steam pressure equal to the water pressure.

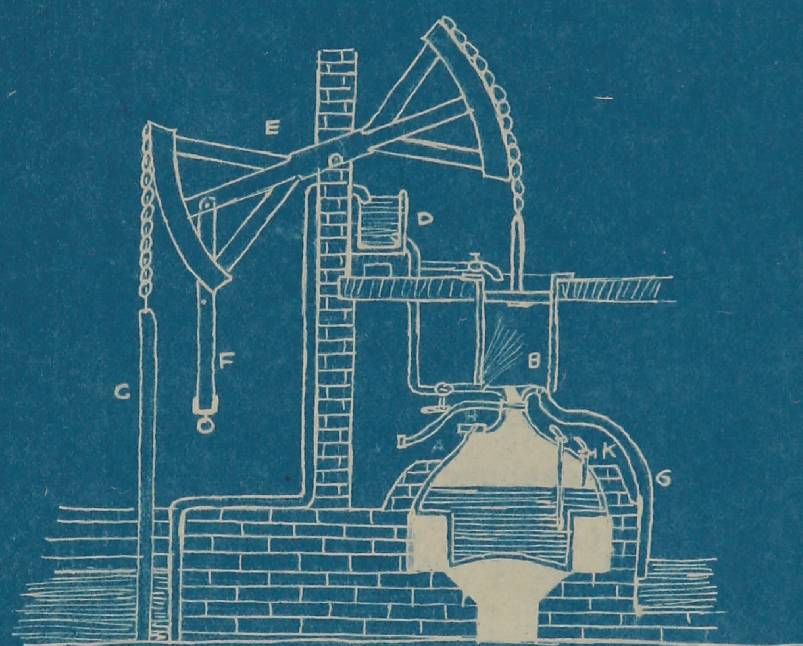
In 1705 Thomas Newcomen first employed the different sized piston in his famous atmospheric engine.

The engine as shown in the figure is operated as follows. Steam was generated at about atmospheric pressure in the tank A. As the piston in B was drawn up by the unbalanced beam E the water plunger C was lowered and steam from A was drawn by suction into the piston chamber B. When, at the end of the stroke, the chamber B was full of steam and the water chamber full of water, a jet of water was sprayed into B which condensed the steam and created a partial vacuum in the chamber. The force of atmospheric pressure on the other side of the steam piston then returned the piston to the starting point and raised the water in C. This engine was the most efficient produced up to this time and its lift

EARLY DEVELOPMENT



FOUNTAIN



NEWCOMEN ATMOSPHERIC ENGINE

FROM - GREENE'S PUMPING MACHINERY

was limited only by the strength of the materials used in it. Newcomen had many failures in his work because of his lack of mathematical knowledge, but his engines were successfully used by Smeaton and operated under lifts as great as 162 feet.

The next developments were made by James Watt (1736-1819) who contributed ideas and inventions which not only improved the machines of that day but have been the basis of practically all modern improvements of the steam engine.

After Watt had studied the work of his predecessors he made quantitative experiments which showed many errors in the design of the pumps of that day. He discovered the loss due to radiation of heat and remedied it by jacketing his vessels with steam and by using non-conducting materials as lagging. He saw that when steam was admitted to such engines as Newcomen's that the walls of the cylinders had to be heated only to be cooled later by the condensation process. His experiments showed him the immense loss of heat in this process and he devised the independent condenser. To operate his condensers successfully, he devised condensate and air pumps. Watt also was the first to employ the expansive power of steam which is the basis of all modern engines except those of small steam consumption such as boiler feed pumps.

In addition to the above inventions, Watt either invented or materially improved the following machines.

1. Engine governors.

2. Steam indicator diagrams.
3. Rotary engines.
4. Mercury and water gauges.
5. Double acting engines.

To gauge his machine Watt introduced and used the term "horsepower" as it is used today. This term, together with the term "duty" already in use at that time, gave means of comparing pumping engines. Duty is defined as the number of foot pounds of useful work done by a definite supply of fuel or power such as one thousand pounds of dry steam.

The next improvement in pumping engines came about 1798 when the Cornish pump was brought out by William Bull and Richard Trevithich. This pump had all of Watt's economies and was much simpler. This pump was in use for a longer period than any other.

To compare the duties of the most famous early pumping engines, together with the dates of their operation, gives a clear idea of their development.

Date	Pump	Duty
1769	Newcomen	5,500,000
1778-1815	Watt	20,000,000
1820	Cornish	28,000,000
1850	Cornish	60,000,000

In the year 1830 the centrifugal pump was successfully operated in New York by a Mr. McCarthy. This was not a new form of pump but this demonstration was among the first successful uses of it. Its theory and design had advanced since about 1680. Rotary pumps of various designs were built but the difficulties encountered in keeping their pistons tight kept them from very widespread use. The hydraulic ram was invented about 1770. Development of the original ram was made by Whitehurst of England. Montgolfier in 1796 designed a ram which is very similar to those used at present. The ram, of course, is not a heat engine.

The history of the modern forms of pumps begins in the year 1840 when Henry R. Worthington began his series of developments. He began by inventing a boiler feed pump for a canal boat. He improved the valve mechanisms of the pumps in a very marked degree from spring thrown valves to the balanced valves of modern engines and the use of the duplex pump with its simplicity of valves. From this point development in waterworks pumps has been rapid and steady. The main types which have come to the front in present design are the reciprocating and centrifugal pumps. In the reciprocating class are the two main divisions of horizontal cross-compound and vertical triple expansion engines. The duties have increased until in a recent installation of a vertical triple-expansion unit in Cleveland, Ohio a duty of 211,000,000 ft. lbs. of work per 1000 pounds of steam was reached, with a thermal efficiency of 24.3 per cent.

Evanston's Water Supply.

During the summer of 1922, the extremely hot weather caused the use of so much water that the peak loads on the waterworks were pushed up to new high values. At that time, the equipment of the Evanston waterworks consisted of two horizontal cross-compound reciprocating pumps and one centrifugal pump. The capacities of the two reciprocating units are 12 and 5 million gallons per day and the centrifugal unit pumps 10 million gallons per day. The two reciprocating pumps were made by the Holly Manufacturing Company of Lockport, N. Y. and the centrifugal by the De Laval Steam Turbine Company.

The combined rate of pumping is then 27 million gallons per day. However, no station ever operates all its units at one time, i.e. some of the units are kept in reserve as standby units in case of breakdown. The normal summer rate of pumping is from 15 to 17 M.G.D. during the peak loads. Using the 12 M.G.D. and the 5 M.G.D. combined the 17 M.G.D. loads can be met. With the 10 M.G.D. and the 5 M.G.D. the 15 M.G.D. loads can be met. This leaves one or the other of the large pumps for standby. However, during 1928 the peak loads ran as high as 19 M.G.D. If, under such loads as these, one of the large pumps were shut down for any reason at all the remaining pumps would fall short of carrying the load and there would be a shortage of water and a decided reduction in the pressure of what water was pumped if any pressure at all was maintained. In this connection it must be remembered that the waterworks pumps directly into the mains and that there is no storage to fall back on.

To meet this condition, then, it became obvious that more capacity was required to insure constant water supply under all loads. It then became the problem of the Waterworks Committee of Evanston to meet the situation. Taking into consideration the growth of the city of Evanston and the village of Wilmette, which are both supplied by the Evanston waterworks, and predicting the future demand it was found advisable to plan on installing a unit of sufficient size to carry the entire present load and allow for expansion. This decision was made partially on the realization that the two reciprocating units now installed are over 30 years old and can not be considered as future security. The 12 M.G.D. pump appears at present, however, to be good for some years to come but the 5 M.G.D. pump can not be rebored again. Hence its service for the future is limited. The decision called for an 18 M.G.D. pump to be installed. The next problem became that of picking the best unit for the work it was intended to do.

Choosing the Unit.

Choosing the correct equipment in the way of the pumping unit is by no means as easy a job as it sounds. Most waterworks are now municipally owned and operated. This means that it is the taxpayers' money that goes to pay for equipment. The return from the sale of water in Evanston is not used to provide for expenditures. Hence the city voted a bond issue to cover the cost of the new unit.

A great number of factors enter into the question of choice of the unit. Some of these factors may be reduced to a money basis such that various types of pumps may be compared readily. It is actually the cost in dollars and cents which is or should be the criterion in a case of this kind. Taking up the problem after the capacity has been decided upon let us look at the other factors.

There are four types of pump which could meet the 18 M.G.D. capacity required by Evanston. They are (1) the vertical triple expansion engine; (2) the horizontal cross-compound engine; (3) the motor driven centrifugal pump; (4) the steam turbine driven centrifugal pump. Two of these types can be immediately eliminated. The vertical triple-expansion engine has far too high a first cost to be considered except in cases where the particular advantage of this type (high duty and high thermal efficiency) are especially demanded. The motor driven centrifugal pump necessitates purchase of power for its operation which would result in prohibitive cost when a steam plant is already installed. The two remaining types (the cross-compound reciprocating unit and the steam turbine driven centrifugal unit) are the ones between which the choice had to be made.

With a station already built, as at Evanston, the first question that arises is that of the space required for each type. Investigation of this point shows that the reciprocating unit requires a space of 44' x 19' exclusive of passage ways around it; whereas the centrifugal unit requires 8' x 18' exclusive of aisle space. This factor is important when space is limited and must be conserved for future use. At Evanston there is room for either type.

Next the question of weights of the units enters when it is seen that concrete foundations have to be constructed properly to install the pumps. An 18 M.G.D. reciprocating unit will weigh in the neighborhood of 217 tons and will require a massive structure of concrete to hold it perfectly rigid under the reciprocating motion of the heavy pistons. The same capacity centrifugal pumps could almost be set on any concrete floor and would operate smoothly. The actual foundation structure constructed for it is small in proportion to that of the other type. The question of the enormous weight of the cross-compound unit brings in the further question of the strength of the building in which it is to be placed. Any alterations such as bracings, shoring, etc. needed to install this unit must be charged to its cost. It would be seldom that alterations would have to be made for the centrifugal type.

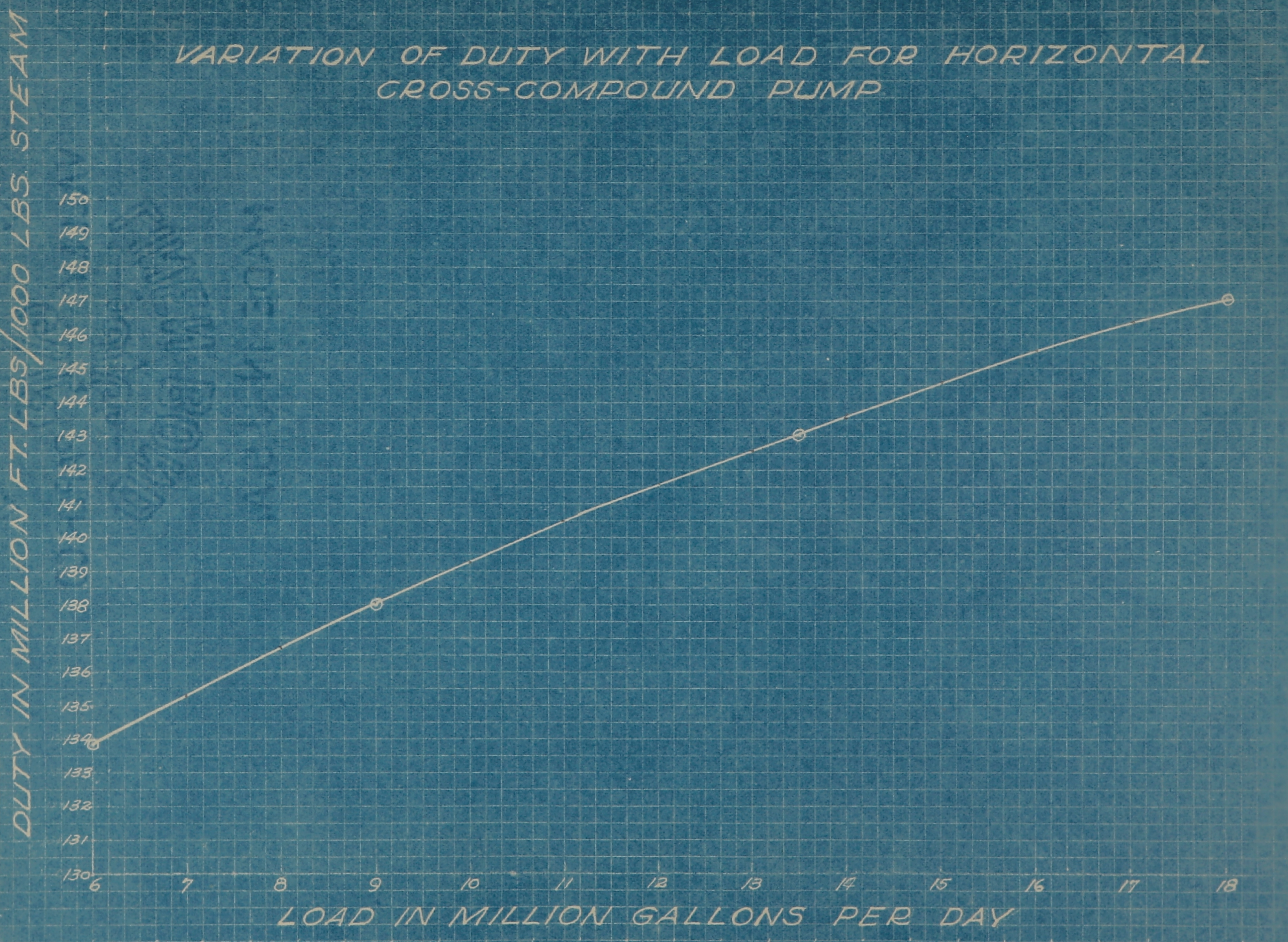
The initial costs of the two types can be readily compared. The reciprocating unit can be installed for approximately $75,000 against an initial cost of $30,000 for the centrifugal unit completely installed. In each case the condensing equipment is included, but the foundations had to be furnished by the city.

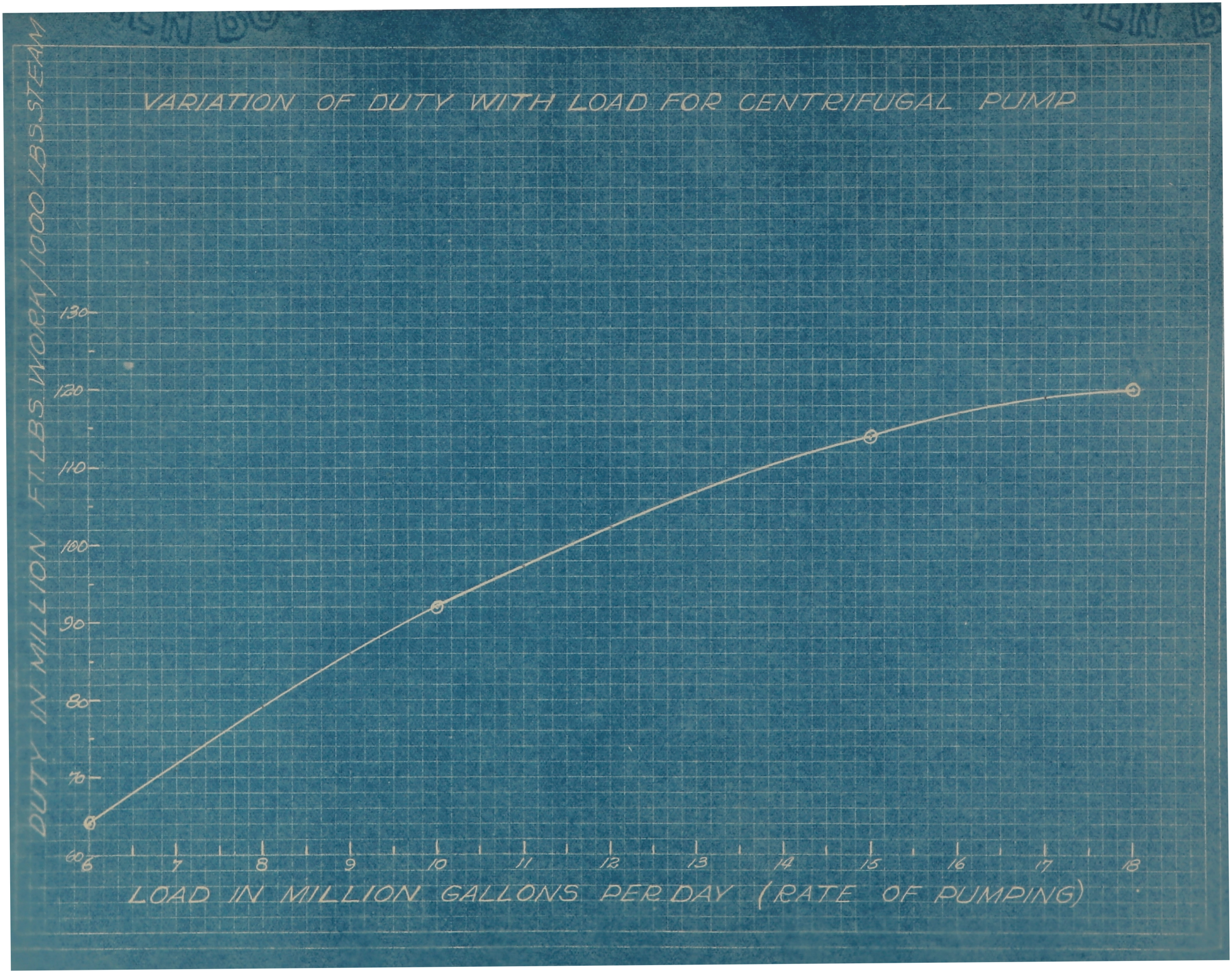
In the matter of duty the reciprocating pump excels the centrifugal. At capacity rating the engine will deliver 148 million foot lbs. per 1000 pounds dry steam against approximately ~~114~~ 120 million for the turbine. This is a very decided advantage in favor of the engine when operating costs are considered. Whether the saving per year in operation of the engine would more than offset the disadvantage of first cost during the life of the units is a matter of computation and will be discussed in detail later. This increased duty brings in another factor which must be given some weight. Increased duty means less expense for coal and less money tied up in coal. This saving should be capitalized in favor of the reciprocating unit. From a purely ethical standpoint, the reciprocating engine is to be preferred to the centrifugal, when the conservation of coal is considered. Less coal used in operation means more left for the future. This question is generally overshadowed by the more definite factors, but it is worthy of consideration to those who have the future welfare of the country at heart.

The load on a pumping station varies within wide limits, from low points in the early morning to high peaks in the summer, when hot and dry weather is conducive to sprinkling of lawns. The pump chosen should meet these conditions easily and economically if possible. Either type of pump seems to be flexible in regard to taking various loads, but the drop in duty is a great deal less as the load falls off on the reciprocating unit than it is on the centrifugal unit. A study of the efficiency curves on the following page will illustrate this point. This again favors the operation costs of the reciprocating unit.

With the capacity chosen as it is for future growth the question of overload is not of great importance. It is claimed, however, that the engine can carry overloads more safely than

VARIATION OF DUTY WITH LOAD FOR HORIZONTAL CROSS-COMPOUND PUMP





VARIATION OF DUTY WITH LOAD FOR CENTRIFUGAL PUMP
DUTY IN MILLION FT. LBS. WORK/1000 LBS. STEAM
130
120
110
100
90
80
70
60
6
7
8
9
10
11
12
13
14
15
16
17
18
LOAD IN MILLION GALLONS PER DAY (RATE OF PUMPING)

can the turbine. This is due to the fact that the engine can be speeded up without much danger to its bearings; whereas the high speed turbine endangers its bearing by further increasing the heat of friction at the high speeds.

When the length of life of the two types of units is taken into account the advantage is again on the side of the reciprocating unit. This is for two reasons. The reciprocating unit is a low speed machine and the wear and tear on its mechanism is practically a minimum. The bearings are often good for the entire life of the unit without replacement. The centrifugal pump with its normal high speed subjects its blades and mechanism to great stress and wear and its bearings to high heats due to friction. Centrifugal pumps have decidedly more bearing trouble than do the reciprocating units. Further, the development of the reciprocating pumps has advanced to a much farther degree than the centrifugal pumps. This means that the obsolescence factor is much less with the engine. To compare these pumps in terms of years of life, it is fair to allow the reciprocating unit 30 year's life against 20 years for the turbine. In each case notable installations have far surpassed these limits but the general case is as above given.

The low speed of the engine as against the high speed of the turbine gives the engine a further advantage of greater reliability. This factor is very hard to reduce to a monetary value, but is of decided importance when a city is being supplied from but one source. The amount of time required for repairs, the frequency of need for repairs, availability of spare parts, and availability of labor for repairs must be carefully considered in choosing the unit. It can be said for the reciprocating unit that its bearing trouble is decidedly less than that of its competitor, but on the other hand the engine requires more time out for packing. The time required for repairs is a dead loss to the operators even if the service being rendered is not impaired.

The reciprocating engine because of its size and complication of mechanism requires more general care and attendance than the centrifugal. However, the city of Evanston already employs enough men in operation of its pumping station to take care of the new unit selected.

A factor entirely in favor of the centrifugal pump is the fact that if any accident occurred in the mains which prevented more water from being pumped into them the impeller of the centrifugal would merely churn the water in its case and cause no damage. Such an accident occurring with a reciprocating unit pumping into the mains would cause a high head of pressure to be developed in the water cylinder great enough to burst the head or walls of it and cause damage. This danger is, however, rather remote and should not sway the decision. Rather that some provision be made to avoid the occurrence if the engine is installed.

There is one more consideration in the question that is next to impossible to reckon in money value. It is the satisfaction of the operating engineers who are to operate the unit. Men do their best work when they are interested and satisfied. If engineers are forced to work on a unit which they do not like the result will be evident in less efficient operation or discontent. It is always possible, but many times far from feasible, to change the engineers. It may be wiser in many cases to spend some extra money to produce satisfaction and trust that the satisfaction will show in better operation, which will in turn produce lower operating costs and overcome the initial handicap.

The weight that should be given to the factors in proportion to each other is determined by the conditions to be met and the viewpoints of those making the decisions. In the case of the city of Evanston the Waterworks Committee, after consulting pump manufacturers and engineers saw fit to purchase from the Allis-Chalmers Manufacturing Company of Milwaukee, Wisconsin, an 18 M.G.D. cross-compound, condensing, high duty, crank and flywheel reciprocating pump. With this choice made and the pump purchased the problem of this thesis, as stated in the introduction, may be begun.

The Pump and Its Costs.

Before attacking the costs of the pump and its operation, the description of the pump should be given. Following are the data on the unit as obtained from the contract between the city of Evanston and the Allis-Chalmers Company.

Specifications

Capacity normal . . . . 18 M.G.D.

Minimum capacity under governor . . . . 7 M.G.D.

Total head normal . . . . .140 feet

Specifications (Continued)

Steam Pressure throttle	160 lbs. per sq. in.
Vacuum not less than	27 in. Hg. (referred to 30 in.barometer)
R. P. M. (at rating)	38
Plunger speed	266 ft. per min.
High pressure cylinder diameter	24 in.
Low " " "	56 in.
Pump plungers diameter	24 3/8 in.
Stroke	42 in.
Main journals	13 in. diameter x 26 in. long
Crank pins	8½ " " x 7½ " "
Crosshead pins	7½ " " x 8½ "" "
Flywheel	16 ft. diameter - 3500 lbs.
Shaft diameter in wheel fit	15 in.
Number of valve cages for each suction and discharge deck. . .	7
Number of valves per cage	21
Diameter pump valves	3 5/8 in.
Lift of pump valves	9/16 in.
Pump valve area each deck	775 sq. in.
Cooling surface of condenser	800 sq. ft.
Valve area in percent plunger area	167
Velocity of water through pump valves at rating. . . .	2.58 ft. per sec.
Air pump attached double	17 in. x 14 in.
Diameter suction nozzle	42 in.
Diameter discharge nozzle	36 in.

<u>Specifications</u> (Continued)

High pressure piston rod diameter	4 3/8 in.
Low pressure " " "	6 in.
Plunger " " "	4 3/4 in.
Steam connection "	5 in.
Exhaust connection "	16 in.
Weight of the unit	435,000 lbs.

Pumping Engine Contract Data.

The pumping unit proper is being paid for in a bond issue of $75,000 bearing interest at four and one half percent per annum.

The alterations on the present pumping station which were made to correctly install the new unit cost very close to $40,000.

Cost of the pumping unit (amount paid A-C Co.) $74,200.00.

The contract required that the A-C Co. furnish, deliver and erect the new unit in the present station.

The pump was guaranteed to be ready for delivery 6 months after the contract was signed, and to be installed and operating within 3 months after the shipment had been made.

Duties Guaranteed for the Pump.

147	million	foot-pounds	of	work	per	1000	lbs.	dry	steam	at	100%	load
143	"	"	"	"	"	"	"	"	"	"	75%	"
138	"	"	"	"	"	"	"	"	"	"	50%	"

Measurements of the water pumped were made on plunger displacements.

Foundations for the unit were erected by the city of Evanston.

Accessories included in the purchase,
- hand operated throttle valve, balanced type with by-pass.
- steam separator and suitable trap
- receiver for steam
- suction, discharge, and vacuum gages
- revolution counter six figures.
- wrenches
- force feed lubricating system
- indicator piping.

The contractor guaranteed to keep the pump in perfect condition in regard to replacing broken or worn parts, etc. for the first year of its operation after the installation.

The number of duty tests was not to exceed three.

Forfeits to be made if guaranteed duty was not reached.
For 1st million ft.lbs/1000 lbs. steam or fraction thereof less than guarantee the contractor forfeits the sum of 1000 dollars on the purchase price.
For the second million or fraction thereof the forfeit is $2000
" " third " " " " " " " $4000

Also before any accuracy of operating costs can be obtained, it is necessary to know how many hours per year the pump will operate at the various efficiencies, i.e. various loads. To determine this point it is necessary to study the load on the station and how it varies by the hour, day and month.

The Evanston pumping station supplies the city of Evanston and the village of Wilmette with water at a pressure of 47 pounds per sq. in. in the mains. As there are no facilities for storing water, the engines pump directly into the mains. The load on the pumps, then, varies exactly as the loads on the mains, i.e. as the water is drawn for use by the consumers. The pumps are run in the station according to the load. When the load exceeds the capacity of the 5 M.G.D. pump one of the large units is started and the small one shut down. The pumps are designed to operate most economically at full rating. Hence the engineers shift the load from one pump to another with the load to meet this condition if possible.

To enable the operators to know at all times the rate of pumping, each pump has a gauge which will tell at a glance what the load is. In the case of the reciprocating pumps the gauge is a revolution counter. Multiplying the revolutions per hour by the piston displacement the rate is determined. For the centrifugal pump the rate is read directly from the Venturi meter dials. Every hour the readings of these meters are recorded on printed forms.

With a year's supply of these forms it is possible to know the rate of pumping at any time during that year or to know how much water was pumped in any particular interval during the year. For this problem, the records of the year 1923 were obtained.

The 8760 hourly readings * were then arranged on specially constructed charts which facilitated the handling of the figures to determine (1) the total pumpage for each day which is also the average rate of pumping for the same day; (2) the hourly average for 24 hour days taken for,

(a) a winter month.

(b) a summer month.

(3) the number of hours during the year that the load averaged 6, 7, 8, 9, 10, etc. M.G.D. The "Curve of Daily Load Variations" on the accompanying blue prints shows graphically the variations which occur from day to day. It will be noticed that on all legal holidays and Sundays the load drops from the general average to cause a low point. These points can be checked against a 1923 calendar for verification. The reason for these slumps in the load on these days is the lack of commercial use of water. This also shows the commercial load to be from a half million to a million and a half gallons per day. The flatness of the curve from January first almost to June first and again after September first indicates that

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* These charts included in original thesis only.
See end. (Appendix)

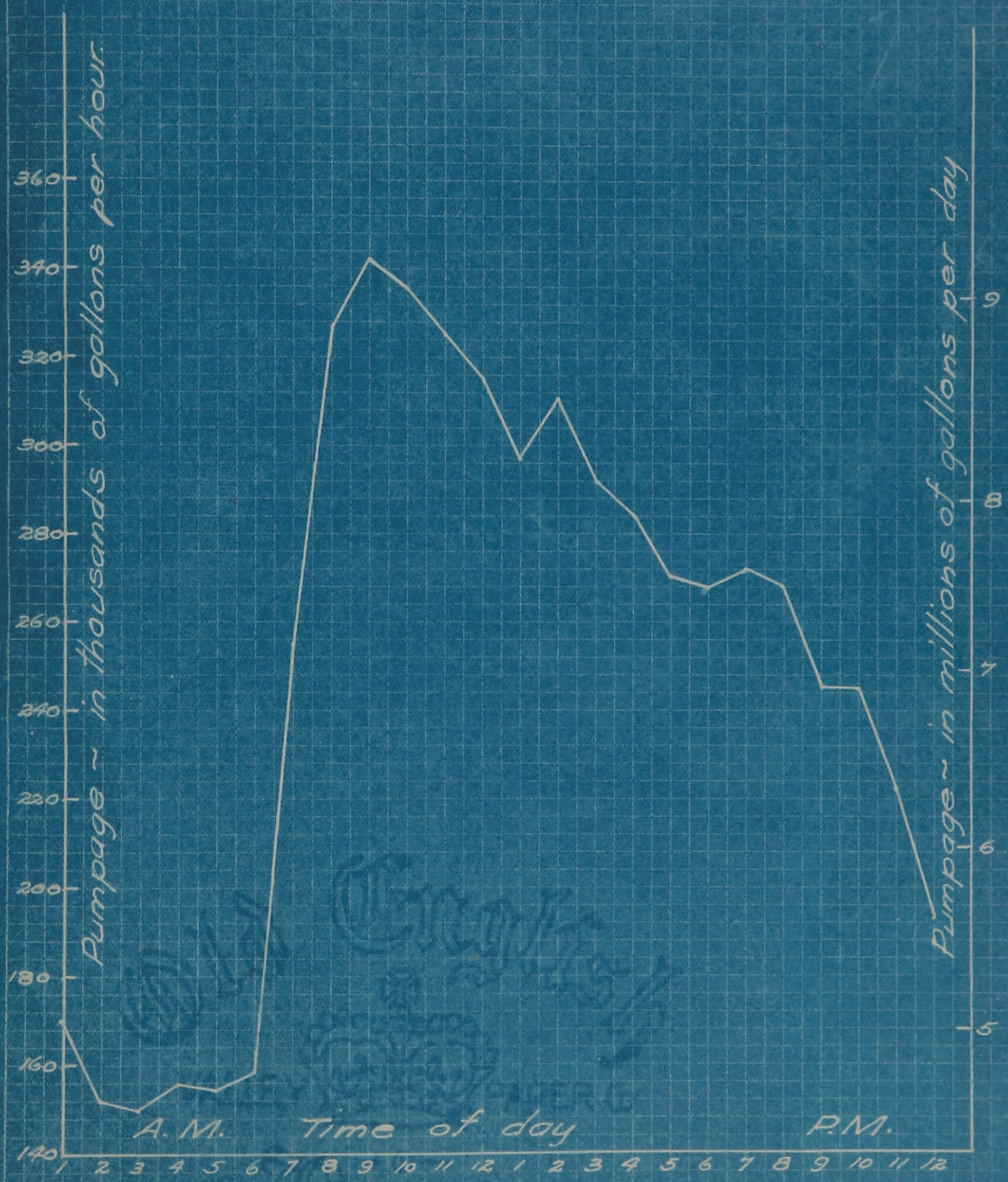
CURVE OF DAILY LOAD VARIATION FOR EVANSTON WATERWORKS - 1923

the weather affects the load very little except in the general hot and dry weather of summer. Between June first and September first the irregularity of the curve is very marked. Investigation of this feature shows that these irregularities are due only in a small part to greater use of water for domestic purposes. They are due to the heavy use of water for lawn sprinkling. Checking the pumpage against the government reports on temperature and rainfall, show that on hot days when there was very little or no precipitation the pumping load was high. On cooler days or when there was a fair to heavy precipitation, making outdoor sprinkling unnecessary, the pumping load assumed nearly normal size.

In considering the two curves of hourly variation throughout the day, the rate of pumping is found to be consistently higher in the average summer day than it is in the winter day. The peaks, however, coincide in the two cases showing that the use of the water, although generally greater in the summer, follows the same curve as the winter load. The lightest loads occur from midnight to six A.M. after which the pumpage rises to the highest peak of the day. From the heavy peak the load falls off until noon, when it again rises a little only to start a further decline lasting until 10 or 11 P.M. Here the load is again sustained for about an hour. This is probably due to the use of water at bed time.

Considering these curves with regard to the minimum capacity of the unit (six million gallons per day) it is shown that during the summer the unit can be operated for a

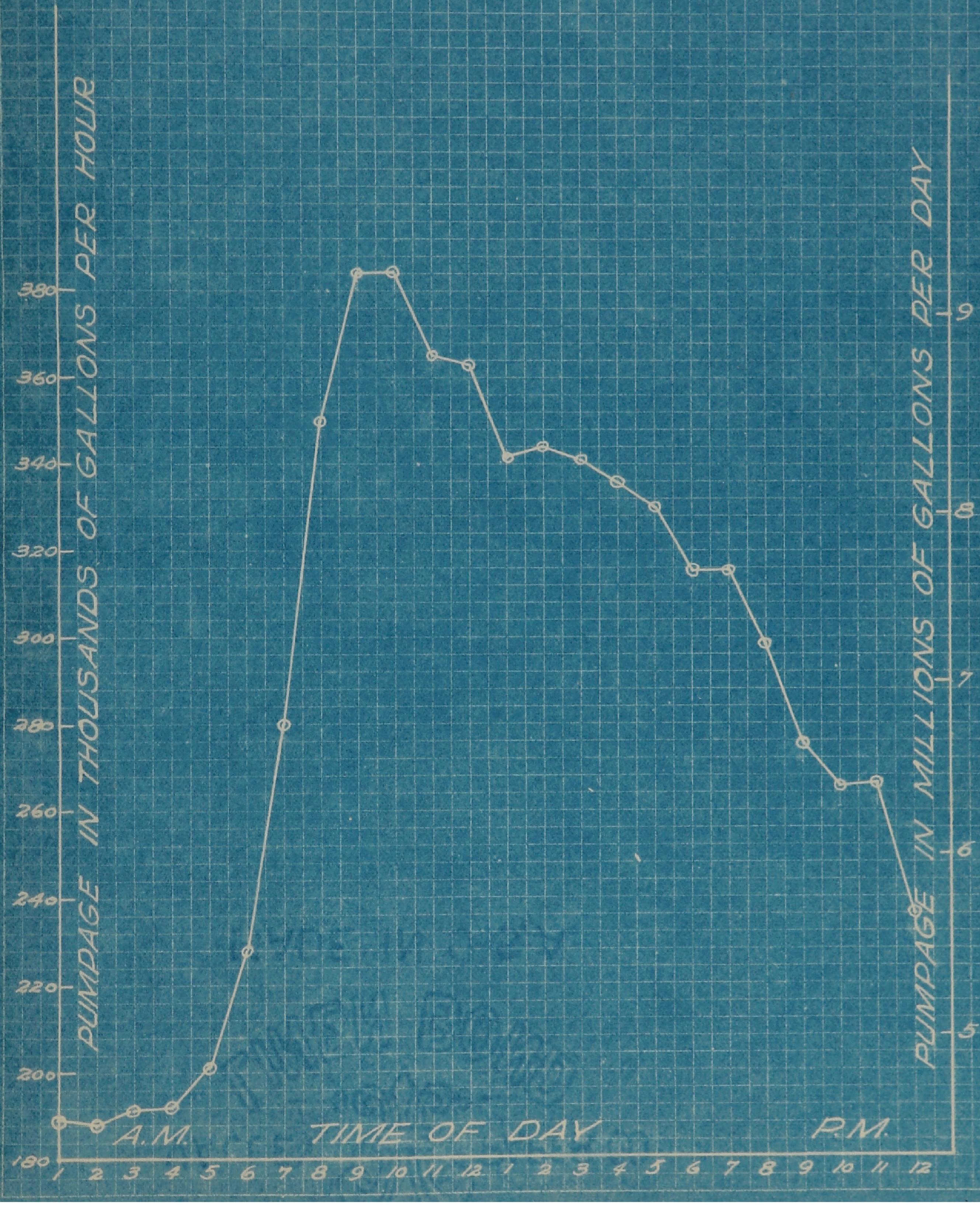
HOURLY PUMPAGE VARIATION CURVE
From averages of January 1923 of Evanston Waterworks.



HOURLY PUMPAGE VARIATION CURVE

From averages of August 1923.

Evanston Waterworks.



daily period of nearly sixteen hours. For the average winter day this period would be cut to about thirteen or fourteen hours. In either case this period would be enough to justify its operation when the high duty of the engine is considered.

These curves give a fair idea of the operation of the unit. To get definite time of operation to compute costs of operation by, it is necessary to count the hours (on the chart of hourly readings) that the engine operated at the rates of 6, 7, 8, 9, etc. M.G.D. respectively. A count of the hours gave the figures below.

Hours of Operation at Various Loads.

Rate of pumping.	Hours per year 1923 at rate.
6,000,000 G.D.	1146 Hours
7,000,000 "	1553 "
8,000,000 "	1457 "
9,000,000 "	1007 "
10,000,000 "	448 "
11,000,000 "	182 "
12,000,000 "	108 "
13,000.000 "	2 "

If these figures are assumed to be a fair representative value for a year, it is possible to determine the cost of coal per year. If the rate in million gallons per day is divided by twenty-four the rate of pumping is found in gallons per hour. Dividing this result by 7.481 (the number of gallons in a cubic foot) gives the number of cubic feet of water pumped per hour. As each cubic foot of water weighs 62.5 pounds, the total weight of water pumped per hour is readily found. The pumps operate against a pressure of 47 pounds in the water mains of the city. This pressure is equivalent to pumping against a head $\frac{47}{.434}$ = 108 feet approximately.

If the weight of water is multiplied by the head pumped against, the answer will be the number of foot-pounds of work that the pump does in an hour when pumping at a certain rate. Multiplying this result by the hours per year that the pump operates at this rate gives the foot-pounds of work done per year when pumping at this rate. Dividing by the duty at the same rate (the number of foot-pounds of work per 1000 pounds dry steam) gives the number of thousands of pounds of steam required to produce this work. If the cost per 1000 pounds of steam is known, the cost of the work of pumping, i.e. the coal which produces the steam which does the work, is readily found.

Incorporating the above in a formula the cost can be determined for all rates by a substitution of but three quantities with a constant for the solution.

$$\text{Cost} = \frac{47 \times 62.5 \times \text{rate} \times \text{hours} \times \$.372}{.434 \times 24 \times \text{duty} \times 7.481}$$

$$= K \frac{\text{rate} \times \text{hours}}{\text{duty}}$$

Hours = hours of operation at rate used.

Duty = duty at rate used (see table).

\$.372 = 37.2 cents = cost per 1000 pounds steam.

Rate M.G.D.	Duty Million ft. lbs. per 1000 lbs. steam Reciprocating Unit.	Centrifugal Unit.
6	134.00	64.0
7	135.25	71.6
8	136.75	79.0
9	138.00	86.0
10	139.25	92.0
11	140.50	97.0
12	141.60	102.5
13	142.60	107.0
14	143.60	111.0
15	144.60	114.0
16	145.50	117.0
17	146.40	119.0
18	148.00	120.0

The results of the computation for the Evanston station loads as applied to the reciprocating engine and the centrifugal pump are as shown below as costs of coal for each.

Rate M.G.D.	Cost of Coal Reciprocating Unit.	Centrifugal Unit
6	$ 719.60	$1506.65
7	1127.18	2139.20
8	1191.08	2070.50
9	921.00	1477.86
10	451.70	683.89
11	199.66	289.45
12	128.44	177.31
13	2.55	3.90
Total	$4741.21	$8348.76

The cost of the steam (37.2 cents per 1000 pounds) is taken from the results of a boiler test made on the boiler plant of the waterworks by Professor H. S. Philbrick, on November 16, 1922. This test was run under the conditions of actual operation of the plant. At that time coal cost $5.71 per ton. Coal is a little cheaper than that now but the figures given above are taken from actual observation and used in preference to any assumed values. No more recent values are available. The evaporation at that time was 7.69 pounds of water per pound of 11,332 B.t.u. coal.

The next item of charge to be made against the units is the allowance made for depreciation. Remembering that the lives of the reciprocating pump and the centrifugal pumps are 30 and 20 years respectively, it is necessary during this period to plan for the payment of the bonds which were sold to pay for the pump. In 30 years, then, the reciprocating unit must produce a fund of $119,200. This figure is the original cost of $74,200 plus $45,000 which was spent in foundations for the pump and the building. It may not be quite correct in all cases to charge the cost of increased foundations of the building to the pump but in this case this expense was solely for the unit purchased and will probably be worthless after the pump is abandoned. The building now housing the pumps will probably be obsolete by the time the present installations are abandoned. This cost is charged, then, to the reciprocating unit. The centrifugal unit requires no excess foundations, merely the base on which it rests. During the 20 years of its life a fund of $40,000 would be necessary. Such funds can be accumulated in a sinking fund to offset this depreciation.

Each year during the life of the unit a certain amount is put aside at compound interest. It is safe to assume that this money will pay a return of 4½ per cent of interest. Then the annuity to provide this sinking fund can be computed from the equation and tables of annuities. To provide a sinking fund of $119,200 in 30 years, when the interest is compounded at 4½ per cent, requires a yearly charge against the reciprocating pump of $1953.84. In a similar manner, it requires a charge of $1275.05 per year to provide a sinking fund of $40,000 in the 20 years life of the centrifugal pump.

In addition to the depreciation charge, there must be a charge to pay the interest on the investment, i.e. the interest on the bonds sold to pay for the unit. The bonds are placed on the public market by some bonding house. The rate of interest paid to the bondholders is 4½ per cent, but to this rate of interest must be added some further interest collected by the bond house for the sale of the bonds. To cover both the interest to the holder and to the seller there must be a yearly charge against the pump. It is assumed that this rate of charge will be 5 per cent of the total investment in each case. To the reciprocating unit, then, will be charged a yearly sum of $5960. To the centrifugal unit the yearly sum of $2000 will be charged.

As before stated, the present amount of labor employed at the pumping station, while not more than necessary to run the present installation, is still enough to operate the new installation without further employment. No charge is placed against either pump, then, for this item.

The charge for oil, waste, supplies and maintenance of the units is quoted from the figures submitted by the Allis-Chalmers Manufacturing Company. These items when applied to the reciprocating pump produce a yearly charge of $800 as against a charge of $400 for the centrifugal units.

The last item of charge to the yearly costs is that of insurance. The rate per thousand dollars of insurance depends on the type of building in which the pumps are installed. The walls and floors of the section in which the new unit is installed are of concrete, but the roof over the entire station, as well as the floor of the old engine room, are of wood. The window and door frames, sash, and doors are also of wood. These wooden features increase the fire hazard and the rate for insurance on the contents of such a construction is increased. The contents of the pumping station could be insured against fire in the present building for approximately $8.00 per $1000 of insurance. This rate means a charge of $592 per year on the reciprocating unit and $320 per year on the centrifugal unit. If the building were remodelled to increase its fire resisting qualities the rate for insurance on its contents could be approximately halved. The saving on the yearly premium would pay a good share of the interest on the money needed to remodel.

The saving on the insurance is not the whole story of the fire danger, however. A fire occurring in Evanston's pumping station would not have to be very serious to cause the wooden roof to fall in on the pumps. Even the small amount of wood in the roof, if placed as a bonfire on the engines, would so warp them and expand them that it is doubtful if they could be again placed in commission. Meanwhile, the city of Evanston and the village of Wilmette would be cut off from water supply for this station is the only source of water for these towns. It is beyond prediction what would occur in such a case.

To compile the yearly costs in order to compare in definite figures the pump installed and the pump which was rejected the figures are incorporated in the table below.

Yearly Operating Costs.

	Reciprocating Unit	Centrifugal Unit
Cost of coal	$4741.21	$8348.76
Interest on investment .	5960.00	2000.00
Annuity for depreciation	1953.84	1275.05
Maintenance, oil, waste supplies	800.00	400.00
Insurance	592.00	320.00
Total yearly cost . .	$14,047.05	$12,343.81

On a strictly cost basis the centrifugal pump has an advantage of $1,703.24 over the reciprocating unit. Against this advantage can be set some factors in favor of the reciprocating pump which can not be reduced readily, if at all, to a monetary basis. These can be weighed for what they are worth to those who have any opinion in the matter. They are as follows.

1. The reciprocating unit is generally conceded to be more reliable than the centrifugal unit.

2. The reciprocating pump will meet the favor of the present staff of the pumping station.

3. The obsolescence factor of the engine is a great deal less than that of the centrifugal pump.

4. The length of life, exclusive of obsolescence, is longer with the reciprocating pump than with the centrifugal pump.

5. The reciprocating unit in using less coal per year saves the city of Evanston the interest on the money which would have had to be invested in coal to keep the centrifugal unit running. This is a direct credit to the engine and can be deducted from its yearly operating costs. The difference in coal costs between the two units is $3607.55. The interest (4½ per cent) on this sum can be called the capitalization of the coal saved, and can be credited to the engine. This amounts to $162.34.

In the opinion of the writer, these factors will wipe out the advantage of the centrifugal pump and justify the purchase of the reciprocating pump.

There is still a question in the case of this particular installation which cannot be solved in this paper from lack of time. It may be possible that the installation of two smaller centrifugal pumps which would meet the demand for capacity, might operate with a duty high enough to cut the operating costs sufficiently to give an advantage to such an installation. This phase of the problem was omitted because it did not appear in the estimates furnished by the companies bidding on the installation. It is obvious, however, that there is a question when the duties of the two large capacities are compared with regard to the present load.

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